ESC-TR-99-046

Technical Report
1057

Airborne Paging Demonstration

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25 March 2000

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS

Prepared for the Department of the Army Communications –
Electronics Command under Air Force Contract F19628-95-C-0002.

This report is based on studies performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology. This work was sponsored by the US Army, CECOM, under Air Force Contract F19628-95-C-0002.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

AIRBORNE PAGING DEMONSTRATION

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Group 60

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ABSTRACT

Personal pagers have found wide-spread use in the commercial world, allowing people on the road or away from their office to be contacted with a simple message, often to "call home." The utility of this service clearly translates to the battlefield. However, the tactical battlefield does not come equipped with the large infrastructure that is used by the commercial systems. For the battlefield, either a satellite-born or an airborne transmitter can be used to activate near-commercial paging receivers. During an earlier program, paging from military communications satellites at UHF was demonstrated. However, the available signal margin was too low for reliable paging, particularly into structures.

This report gives results from a recent demonstration using an airborne platform with a standard UHF radio as the paging transmitter and the paging receivers from the previous program. These airborne tests took place in March and June 1999. With only a two-watt transmitter at an altitude of 17,500 feet, paging at up to 40 miles was reliable to receivers unobstructed by high-loss buildings. This was seen for paging receivers at both Lakehurst Naval Air Station and the Myer Center at Ft. Monmouth. For pagers inside of the heavy concrete and steel building of the Myer Center, reception was more sporadic, but improved considerably at shorter ranges (10 miles). It is straight-forward to predict that using a 200 watt transmitter and flying at a higher altitude (say 35,000 ft), reliable paging can be expected at ranges of at least 80 miles and reliable paging into dense buildings can be expected at ranges of at least 40 miles.

ACKNOWLEDGMENTS

The author wishes to acknowledge the contributions of those who made this demonstration possible. Thomas Shake, Warren Hutchinson, and Gloria Liias at Lincoln Laboratory provided corporate memory from the previous phase of the paging program and software support to recreate the Paging Control Center process. Stefano DiPierro of Booz-Allen & Hamilton was instrumental in bringing the aircraft repeater system online, and was supported ably by the aircraft crew at Lakehurst Naval Air Station.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. BACKGROUND AND OBJECTIVE

Personal pagers have found wide-spread use in the commercial world, allowing people on the road or away from their office to be contacted with a simple message, often to "call home." The utility of this service clearly translates to the battlefield. However, the tactical battlefield does not come equipped with the large infrastructure of transmission towers and backbone telephone lines that is used by the commercial paging systems. For the battlefield, either a satellite-born or an airborne transmitter can be used to activate near-commercial paging receivers. During an earlier program [1] sponsored by the US Army, the use of UHF Satcom as the on-orbit transmitter was demonstrated, with modified commercial-like receivers built by Motorola. A demonstration Paging Control Center was also built (by Lincoln Laboratory) that accepted paging requests by e-mail and sent the appropriate uplink to the UHF transmitter on orbit. This test system was successful, but the downlink signal strength was marginal in many situations, particularly when the paging receiver was inside a building. An alternative to the satellite transmitter is an airborne repeater, which is the focus of this current demonstration. By using the same Paging Control Center software and the same UHF paging receivers, it should be possible to use a standard military UHF radio (the PSC-3 in particular) to achieve a much higher margin of signal strength because of the much shorter range from the aircraft to the paging receiver. This should lead to greater reliability of pages and significant ability to penetrate buildings and foliage. In fact, operation in the military UHF band, which is lower in frequency than commercial paging frequencies, ought to have superior penetration capability for the same clear-field signal margin. The airborne tests that are reported on here took place in March and June 1999, using CECOM airborne assets and the previously-developed Motorola UHF paging receivers.

The objective of the current paging demonstration was to verify that an airborne platform carrying standard military radios can provide a reliable paging system and to assess the functional range and penetration capability. This was a minimum-effort demonstration that made use of available assets. It was a technical demonstration as opposed to an operational demonstration involving troops in an exercise.

2. CONFIGURATION

2.1 System Overview

The airborne paging demonstration system had three components: 1) a laptop computer running the Paging Control Center software that accepted paging requests and generated a POCSAG-compliant bit stream for transmission by a PSC-3 radio, 2) an Airborne Node that carried two PSC-3 radios, one to receive the uplink from the Paging Control Center and one to transmit down to the paging receiver, and 3) multiple Paging Receivers that were built by Motorola during the previous program.

2.2 Paging Control Center

The Paging Control Center was previously implemented by Lincoln Laboratory during the earlier satellite paging demonstration program [1] as software running on a UNIX workstation. The Control Center was interfaced to the Lincoln Laboratory e-mail system, and e-mail was used as a paging request mechanism. The e-mail request could originate at any e-mail-capable location (not just at Lincoln Laboratory). In order to provide access control (to prevent spoofing or unauthorized pages), a paging client software program was installed on any computer needing to originate a paging request. This client allowed the computer user to enter a paging request by giving just the paging receiver ID and a 20-character message to be sent to (and displayed on) the paging receiver. The client then generated an e-mail transmission to the Paging Control Center, with the contents encrypted by software (Pretty-Good Privacy). When received at the Paging Control Center, the e-mail message was decrypted and the two parameters (ID number and 20-character message) extracted. The Paging Control Center computer then generated a bit stream that could (through a format-conversion interface box) drive the uplink transmitter to the satellite. The format of the bit stream sent over the air was the commercial POCSAG standard, which is what the paging receivers were designed to receive. The actual throughput of the paging signal is 150 bps, but since the satcom system used had a 1200 bps BPSK transmit mode, the output of the computer repeated each individual bit of the 150 bps message eight times.

For the airborne tests at Ft. Monmouth completed this year, it was decided to minimize the effort in configuring the Paging Control Center and the client e-mail computers, since there was nothing new to learn here. First, the software for the Paging Control Center was moved from a desk-top Unix machine to a lap-top Unix machine which could easily be transported to Ft. Monmouth after being thoroughly tested. The e-mail interface to the Paging Control Center was not used; instead, a number of "canned" e-mail messages were stored on the Paging Control Center computer and were invoked by a simple manual interface by the Paging Control Center operator. The computer then processed these "canned" messages just as if an e-mail had been received. The choice of "canned" messages included individual pages to each of the receivers participating in the

airborne test as well as a "universal" page message that was received by all of the paging receivers at once. The serial-port output (0 and +5 volt) from the Paging Control Center computer was connected to an interface box that converted the serial port format to that needed by the PSC-3 UHF radio (+ and - 5 volt outputs, with transmission at a steady 1200 bps rate).

For an early test of the airborne paging process, a simple fixed (and repeating) message that contained the universal page was stored in a Fireberd bit-error-rate tester (BERT), which could drive a PSC-3 radio directly. When the PSC-3 radio was tuned to transmit at the paging receiver frequency (250.75 MHz), then the signal from the BERT would trigger the paging receivers; this was a useful test mode. (The BERT was also used through the airborne UHF repeater configuration as a preliminary end-to-end test.)

2.3 Airborne Node

The Airborne Node was an existing C-12 aircraft controlled by CECOM operating out of Lakehurst Navel Air Station which carried two PSC-3 radios. One was tuned to receive the UHF signal transmitted from a PSC-3 radio driven by the Paging Control Center computer located outside the aircraft hanger at Lakehurst. The (digital) output signal from this airborne radio was used as input to the second PSC-3 radio on the aircraft, operating in a 1200 bps BPSK format, and transmitting at 250.75 MHz (the receiving frequency of the paging receivers). The PSC-3 downlink radio can operate in either a 2 watt or a 20 watt mode, but the 2 watt mode was used to reduce transmit to receive isolation problems (self-jamming) in the available aircraft installation. The two radios are connected to separate blade antennas, and can be operated simultaneously at this lower power.

A separate air to ground voice radio was used to coordinate the experiment with the pilots and crew.

2.4 Personal Pager

The Paging Receivers (Pagers) that were utilized in this demonstration were selected from the 30 that were acquired from Motorola under the previous program. Fourteen were used. They expect a 150 bps BPSK signal at 250.75 MHz, with the data bits in the commercial POCSAG format. They have a 20 character display of the received paging message. The meaning of the 20 numbers would be determined by military protocols. For the purpose of the demonstration, a random number was sent and the received message written down for later verification.

2.5 Paging Link Calculation

The following simple calculation gives the margin available for terrain losses from an aircraft at 50 miles range from the paging receiver. It is an optimistic calculation in that it assumes that signal strength decreases only as the square of the range; that is, a free-space loss calculation.

Airborne Transmitter	2 w	
Tx Antenna Gain	3 dBi	
EIRP	6 dBw	
Path Loss (50 mi)	-119 dB	free-space at 250 MHz
Rx Antenna Gain	-18 dBi	
Rx Noise (300°)	-203 dBw/Hz	
Data Rate (150 bps)	21.8 dBbps	
Eb/No	10 dB	
Available Terrain Margin	40.2 dB	

In reality there will be excess loss because of the near-ground path encountered by the signal. (For commercial cellular systems, it has been shown that signals effectively decrease as the range raised to the power of 3.5 due to this effect.) At a 50 mile range with the aircraft at 20,000 feet, the elevation angle of the arriving signal is only about four degrees above the horizontal. At this elevation angle there could be significant signal shadowing from hills, and if the receiver were in a forest, the signal would have to travel a long way through the trees at a five degree angle before it would reach the receiver. Whatever the actual propagation margin is, there is also the losses in penetrating structures; the more steel and concrete in the building the more the loss. (In the Ft. Monmouth tests, some of the receivers were in the Myer Center, which is a large concrete structure.) These loss numbers are difficult to quantify. At the experimental frequency of 250 MHz, the wavelength is about one meter. That means that in a building there can be multiple signal paths to the paging receiver which can add or cancel each other; moving the receiver on the order of one meter can result in the composite signal changing significantly. Therefore two receivers in a room separated by even small distances can have significant differences in their ability to receive the page, making it difficult to quantify paging performance from only a few trials. Commercial paging systems which transmit from towers are usually designed with margins of 60 dB or more over free space, and even then they do not always succeed in reaching their receiver. For an operational airborne paging system, the transmitter power could easily be increased to as much as 200 watts, providing 20 dB more margin than in the calculation above.

3. PRELIMINARY TESTS

3.1 Preliminary Testing at Ft. Monmouth

Initial tests to verify the fundamental operation of the paging system were performed at Ft. Monmouth. A universal paging message was stored in a Fireberd bit error rate tester (BERT) and used to drive a PSC-3 UHF radio. All of the available paging receivers were placed near-by. Any pager that failed to respond to the universal page was eliminated from the experiment. There was, however, no quantitative measurement of the paging receivers' sensitivity; there could have been differences among pagers. (One of the design difficulties encountered by Motorola was the fact that when the pager and its antenna are only a small fraction of a wavelength, it is hard to predict the efficiency of antenna coupling to the radio signal. Typical effective antenna gain can be -20 dBi, compared to 3 dB for an ideal half-wavelength antenna.)

3.2 Preliminary Testing at Lakehurst

The next test was on-the-ground to verify that the two PSC-3 radios installed in the aircraft operate properly as a translating transponder. The Fireberd BERT was brought to the Lakehurst hanger where a PSC-3 radio was installed and connected as it was at Ft. Monmouth, except that the transmit frequency was set to a different frequency that matched the receive frequency of one of the PSC-3s on the aircraft. The output of this aircraft receiver was cross-strapped to the input of the other PSC-3 radio on the aircraft. (Both of the on-board radios were operated in the 1200 bps BPSK mode.) The second radio was tuned to transmit on 250.75 MHz. Once again the universal paging message in the BERT was used to test that the correct signal was making it through the complete relay path, and that the paging receivers responded to it. However, there was no quantitative signal strength or margin measurements made; such measurements are difficult at best.

Soon thereafter, this experiment was repeated with the aircraft in the air and the paging receivers on the ground at various locations in and around the hanger. Good success was reported with receiving the universal pages both inside and outside the hanger at ranges up to about 40 miles.

On June 23, 1999, the Paging Control Center computer with its interface box was brought to the Lakehurst hanger and the ground relay test was repeated with the paging signals coming from the computer rather than the BERT. Both universal pages and individual pages to each of the available paging receivers were tried. After some false starts and a software reconfiguration to avoid a buffer underflow problem, the test was successfully completed. Only the 14 paging receivers that responded both to universal pages and individual pages were set aside to be used the following morning in the actual airborne test. All but two of these receivers were sent to Ft. Monmouth to be distributed

around the Myer Center the next morning. Note that the test did not quantify the sensitivity of the receivers; the signal strength during this test was very high since the transmitter was only a short distance from the receivers.

4. AIRBORNE DEMONSTRATION

4.1 Configuration

In the airborne demonstration on June 24, 1999, the PSC-3 radios on board the aircraft were connected exactly as was done in the preliminary tests at Lakehurst, so that one was receiving 1200 bps BPSK, and the other was transmitting the output of the first receiver at 1200 bps BPSK at 250.75 MHz. The Paging Control Center Center computer was at Lakehurst, next to the location of the ground PSC-3 radio. This set-up was a short distance outside hanger number five, where the aircraft was kept. The transmit antenna was placed about 10 feet in the air on the corner of a small building next to the hanger. The Paging Control Center and its interface box were set so that the PSC-3 would transmit 1200 bps BPSK at the frequency being received onboard the aircraft. One working paging receiver (number 15) was at Lakehurst; the remaining receivers were in and around the Myer Center at CECOM, some 24 miles to the northeast.

4.2 Procedures

After checking again that all equipment was operating by successfully receiving pages on the receivers at Lakehurst, the aircraft took off from Lakehurst at about 9:30 AM and flew on a heading toward Ft. Monmouth at an altitude of 17, 500 feet flying under VFR. (The day was clear and sunny.) The on-board radios were turned on in the modes specified above before takeoff, and the Paging Control Center began transmitting pages. Pages were manually initiated from the Paging Control Center computer. A sequence of 4 universal pages separated by about 30 seconds was initiated, followed by a sequence of individual pages to each of the paging receivers. (This sequence of individual pages took about 4 minutes to send.) The combination of 4 universal pages followed by the sequence of individual pages was repeated about every 10 minutes until the aircraft returned to Lakehurst at noon. A log was kept of the paging times and what type of page was sent. Likewise a log of successful receptions by the paging receiver at Lakehurst was kept. Initially the paging receiver was next to the hanger; later it was moved around inside the hanger and outside as well. The separation time between pages was sufficiently long that close synchronization of watches was not necessary to correlate reception of pages with transmission of pages. Flight operations were coordinated with a voice link between the aircraft and the hanger at Lakehurst, so aircraft location was always known and it could be directed to fly to different locations. There were several phone calls with paging receiver operators at the Myer Center to get a preliminary indication that pages were indeed being received. This information was used to redirect the aircraft.

The detailed flight plan that was flown is shown graphically in Figure 1, which shows the major waypoints where the aircraft went into a circular holding pattern. The aircraft taxied out from the hanger area at 9:30 AM, was airborne at 9:36 AM, and

climbed to 17,500 feet altitude. The aircraft then flew on a NW heading about 23 miles until reaching the Great Adventure amusement park at 9:58 AM. After circling over Great Adventure, at 10:26 AM the aircraft turned to the ENE and proceeded to Allaire airport, arriving at 10:26 AM. It circled Allaire until 10:39 AM, and then proceeded to the NW, arriving over Princeton at 10:46 AM. The aircraft circled Princeton until 11:04 AM, and then proceeded to the NNW, arriving over Soleberg at 11:08 AM; sometime during this period the airborne transmitter was inadvertently turned off for a couple of minutes. The aircraft circled Soleberg until 11:25 AM, and then proceeded to

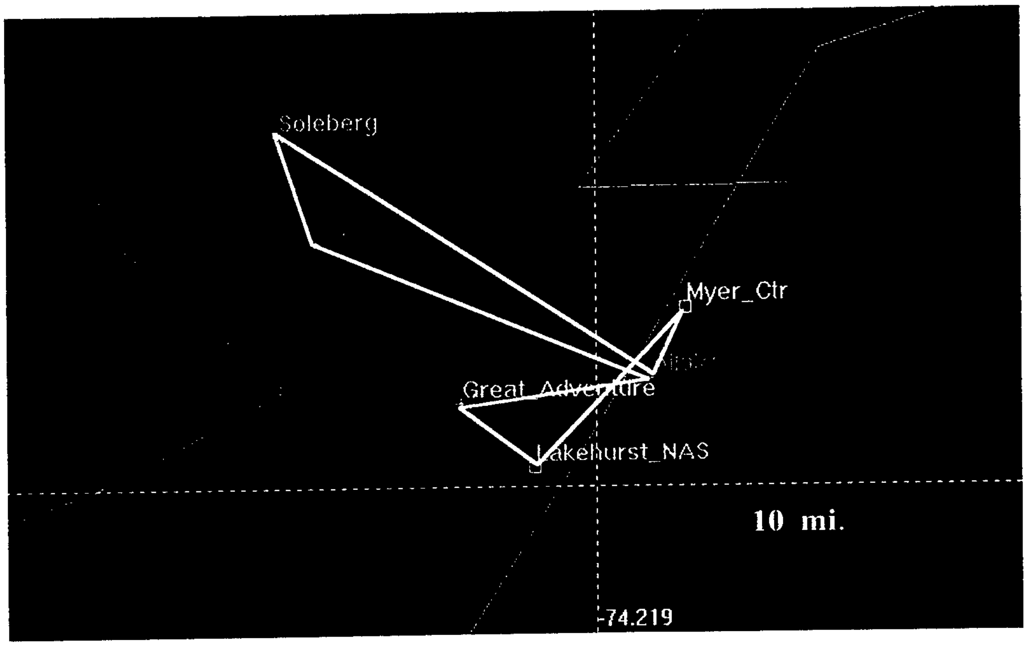

Figure 1. Geographic Distribution of Pagers and Aircraft Locations

FROM	Myer Center			Lakehurst		
TO:	**AZ (deg.)**	**EL (deg.)**	**Range (mi.)**	**AZ (deg.)**	**EL (deg.)**	**Range (mi.)**
Allaire	199.8	20.98	9.2	44.9	12.6	15
Great Adventure	241	8.2	22.7	319.8	18.4	10.4
Princeton	283.3	5.5	33	324.1	5.7	32.2
Soleberg	299.2	4.4	40.5	329.9	4.0	44.1

Table 1. Azimuth, Elevation and Range Relationships

the SW, arriving over Allaire at 11:36 AM. The aircraft circled Allaire until 11:46 AM, and then proceeded to the NNE until it was over the Myer Center at 11:48 AM. At this point, the aircraft immediately turned to the SW and flew directly to Lakehurst, put its wheels down at 11:49 AM, and landed at Lakehurst at 12:02 PM. Table 1 shows the direction, elevation angle and distance from the Myer Center and from Lakehurst to each of the waypoints. Note particularly the low elevation angle at the longest ranges.

During the aircraft flight, paging transmissions were relayed from the Paging Control Center outside of hanger number 5 at Lakehurst. The pages and the times at which they were sent are shown in Table 2. A Universal Page causes all paging receivers to respond; Universal Pages were sent out in groups of four. Alternatively, a series of pages directed individually to each of the pagers was sent in order to demonstrate the ability to address individual receivers; it took about 4 minutes to transmit all of these. (At the beginning, individual pages were sent to paging receivers number 14 and 15, the ones at Lakehurst, to test the link. Paging receiver #15 worked, but paging receiver #14 did not; both had worked in the previous day's tests. Pager #15 continued to work during the rest of the flight, and demonstrated reception at Lakehurst in a number of locations.)

Time	**Type of Page**
9:43 AM	Page #15 twice
9:45 AM	Page #14 twice
9:50 AM	Universal page four times
9:55 AM	Page #14 twice
9:58 AM	Page each pager once
10:05 AM	Universal page four times
10:09 AM	Page each pager once
10:16 AM	Universal page four times
10:22 AM	Page each pager once
10:28 AM	Universal page four times
10:31 AM	Page each pager once
10:44 AM	Universal page four times
10:49 AM	Page each pager once
10:59 AM	Universal page four times
11:05 AM	Page each pager once
11:13 AM	Universal page four times
11:16 AM	Page each pager once
11:23 AM	Universal page four times
11:27 AM	Page each pager once
11:33 AM	Universal page four times
11:36 AM	Page each pager once
11:42 AM	Universal page four times
11:46 AM	Page each pager once
11:52 AM	Universal page four times

Table 2. Paging Transmission Times and Types

Meanwhile, at the Myer Center at Ft. Monmouth the paging receivers were distributed to operators along with a log sheet to record the successful reception of pages, indicating the time of the reception, the pager location, and the paging message (which was always the same 20 character message). Operators were stationed at various laboratories and offices in the Myer Center and on the grounds around it. One was even put into the trunk of an automobile. Most operators moved their location during the

course of the experiment. Figure 2 shows the layout of the Myer Center, the location of rooms where paging receivers were located (all on the fourth floor: the top floor), and directions from the Myer Center to each of the waypoints over which the aircraft circled. Note that the building is about 70 feet wide from the interior courtyard to the exterior, and has two interior corridors, offices on the outside, and labs on the inside; this gives some indication of the amount of building that the signal had to traverse. The building is reinforced concrete; calculation of actual loss is difficult, however, as there may be several paths (windows, reflections, etc.) by which the signal reached the paging receivers. Not surprisingly, the best reception was by a window to the courtyard (4D325A).

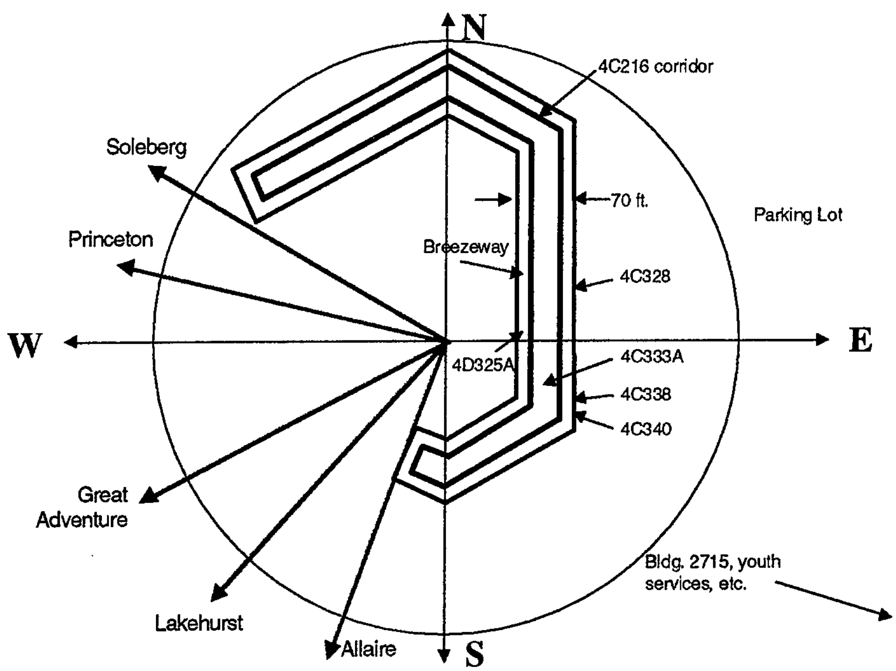

Figure 2. Myer Center at Ft. Monmouth

5. DEMONSTRATION DATA

Table 3 shows the results of the paging experiment. The first column indicates the time and type of page (Universal or List). The time is the starting time of the block of pages. The Universal page took about 2 minutes to send four "all respond" messages. The List page took about 4 minutes to send one specifically addressed page to each receiver. The second column gives the aircraft location at the time the page started; if the next entry is blank, it means the aircraft had not changed location. (A more accurate time-line of the aircraft flight plan was previously given in Section 5.2.) The succeeding columns give the response of each of the functioning paging receivers to the airborne transmission. For universal pages, the number of receptions recorded is shown (maximum is 4). For the List page, only one receiver response should be generated; this is indicated by a "Y" (yes). Also shown is the location of the paging receiver; if the following entry does not show a location, the location should be assumed not to have changed.

As is obvious from Table 3, there is a great variability in the pager response. It is believed that this variability is due to both the receiver location and to the paging receiver operation. There were some pagers that experienced a very high rate of successful reception. For example, pager 13 which was placed in the window of room 4D325A, which looks out on the building courtyard in the general direction of the airplane. Pagers 17 and 31 were in this same location for part of the experiment, and they, too, got good reception there. The result from pager 15 at Lakehurst was also very good. Here the receiver was moved around the base as well as being inside and around Hanger 5, which is basically a very large wooden structure with minimal metal supports. The only time significant misses were made by pager 15 was when the aircraft was at its maximum range near Soleberg (44 miles) at a low 4 degree elevation angle. Pager 38 which was outside at the Myer Center was also very successful, with misses only at the experiment's maximum range (40 miles); the reason for its misses at the start of the experiment are not clear. On the other hand, pager 23 was also outside at the Myer Center and did not do nearly as well. We certainly know that some of the operators had trouble with operation of their pagers. Each time a page is received, it can be cleared manually by pushing one of its buttons. But if the rubber button is pushed too hard, it can get stuck underneath the pager case which then interferes with operation. Some operators responded to this kind of problem by removing the pager battery to reset it. Removal of the battery also resets the internal clock of the pager to 12:00, so subsequent paging times were sometimes reported incorrectly, or the time from a wristwatch was substituted. Not all of the operator logs clearly identified these problems. Pagers that were taken to rooms on the opposite side of the building from the direction to the aircraft generally performed poorly. These rooms included 4C338 and 4C340; signals had to pass through at least 50 feet of building material to reach the paging receiver in these rooms. Pager 17 in room 4C333A did somewhat better; it was located in the laboratory in the middle of the building and so did not experience as much loss as those at the far side of the building, but more loss than

those next to the courtyard (in the aircraft direction) in room 4D325A. There is also doubt that all paging receivers were equally sensitive. Their sensitivity was not quantified in the pre-flight tests at Lakehurst; rather just success or failure was noted at a range of only 30 feet from the aircraft.

Page Time/Type	Pager # Location	13 Myer Ctr	15 Lakehurst	16 Myer Ctr	17 Myer Ctr	22 Myer Ctr	23 Myer Ctr	31 Myer Ctr	32 Myer Ctr	33 Myer Ctr	34 Myer Ctr	38 Myer Ctr
9:58 AM List	At Great Adventure		Y; outside Lakehurst		Y 4D325A					Y outside		
10:05 AM Universal		4 4D325A	4	1 outside	4		4 Outside	4 4D325A		3		
10:09 AM List		Y	Y						Y outside			
10:16 AM Universal		4	4	2				1	1	1; outside bldg 2715		
10:22 AM List	At Allaire	Y	Y		Y 4C333A			Y 4C340		Y park lot	Y 4C338	
10:28 AM Universal		4	3 in car		4	2 4C340	4		1	3	1 3C328	
10:31 AM List		Y	Y		Y	Y	Y			Y car trunk		Y outside
10:44 AM Universal	To Princeton	4	2; inside Lakehurst							1	3; corridor 4C216	4
10:49 AM List	At Princeton	Y	Y		Y							Y
10:59 AM Universal		4	1		1		4					2
11:05 AM List	To Soleberg		Y				Y					Y
11:13 AM Universal	At Soleberg	4	2		1							1
11:16 AM List		Y										
11:23 AM Universal		4	2; outside Lakehurst									4
11:27 AM List	To Allaire	Y	Y		1							Y
11:33 AM Universal	At Allaire	2	3								3 4C338	4
11:36 AM List			Y		Y							Y
11:42 AM Universal			3				1			4 car trunk	1	4
11:46 AM List	Over Myer Center		Y				Y			Y		Y
11:52 AM Universal	Returning Lakehurst		4				4					4

Table 3. Paging Demonstration Results

6. CONCLUSIONS

The airborne paging demonstration described in previous sections successfully showed the potential application of paging from an airborne platform in a tactical theater. Ordinary military airborne UHF radios were used coupled with COTS-derived paging receivers that were pocket-sized. With only a two-watt transmitter at an altitude of 17,500 feet, paging at up to 40 miles was reliable to receivers unobstructed by high-loss buildings. This was seen for paging receivers at both Lakehurst Naval Air Station and the Myer Center at Ft. Monmouth. For pagers inside of the heavy concrete and steel building of the Myer Center, reception was more sporadic, but improved considerably at shorter ranges (10 miles; Allaire). A ground to air link operating at UHF was used to relay the pages generated by the Paging Control Center computer at Lakehurst to the aircraft at ranges up to 44 miles; longer ranges for this link would not have been a problem.

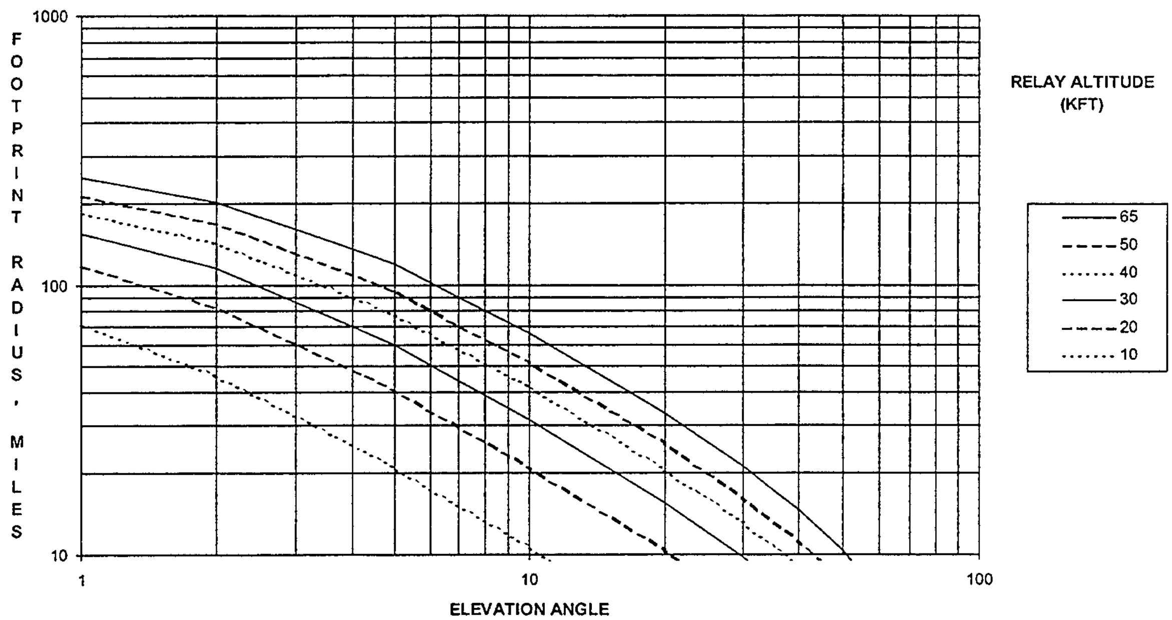

Figure 3. Aircraft Elevation Angle vs Range for Various Aircraft Altitudes

Extension of this demonstration to operational scenarios is relatively easy. First observe that the airborne transmitter was operating at two watts. With a larger power amplifier and a better antenna, transmission at 200 watts could be readily achieved. This extra factor of 100 in transmitted power could provide 20 dB more receive margin to enhance building penetration significantly. In the demonstration described in this report, penetration of the thickest part of the building was obtained at 10 miles range. If received signal falls off as range to the 3.5 power (instead of as range squared, due to the near-earth path), then the factor of 100 in margin could be translated conservatively to a factor of 3.7 in range. Thus penetration of even the very dense Myer Center could be accomplished at a range of 37 miles with a 200 watt transmitter. Furthermore, the range to outdoor receivers could be extended by the same factor of 3.7 to 150 miles, except that at this range the elevation angle would be too low: below 1 degree (Figure 3). Reception could also be improved by flying at a higher altitude. By flying at 35,000 feet instead of 17,500 feet, the transmission distance for the same elevation angle is almost doubled (not exactly doubled, due to earth

curvature). This means that outdoor reception range could easily reach to 80 miles. (This factor of 2 is at the range with the same elevation angle of 4 degrees; the factor of 3.7 increase in range from power limitations to 150 miles still might not be reached due to limitations of the low elevation angle of 1.5 degrees. Flying at even higher levels would increase the angle.) It is also certain that higher altitude would mean that more of the signal path would be above the near-earth effects, and power would only decrease with range squared in this higher regime. Thus both the outdoor reception and penetrating capability would likely be better at higher operating altitudes than indicated by the conservative calculation done here.

In summary, the use of airborne paging UHF transmitters at militarily significant ranges would result in reliable pages being delivered to forces in the field. The engineering of such a system is straightforward, based on the results of the demonstration described in this report.

REFERENCES

[1] Thomas H. Shake, Worldwide Direct Broadcast SATCOM Paging, MILCOM 1997, Pages 69-74.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	25 March 2000	Technical Report

4. TITLE AND SUBTITLE

Airborne Paging Demonstration

5. FUNDING NUMBERS

F19628-95-C-0002

6. AUTHOR(S)

Charles W. Niessen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Lincoln Laboratory, MIT
244 Wood Street
Lexington, MA 02420-9108

8. PERFORMING ORGANIZATION REPORT NUMBER

TR-1057

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

US Army
Communications-Electronics Command
Ft. Monmouth, NJ 07703

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

ESC-TR-99-046

11. SUPPLEMENTARY NOTES

None

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

This report gives results from a recent demonstration using an airborne platform with a standard UHF radio as the paging transmitter and the paging receivers from the previous program. These airborne tests took place in March and June 1999. With only a two-watt transmitter at an altitude of 17,500 feet, paging at up to 40 miles was reliable to receivers unobstructed by high-loss buildings. This was seen for paging receivers at both Lakehurst Naval Air Station and the Myer Center at Ft. Monmouth. For pagers inside of the heavy concrete and steel building of the Myer Center, reception was more sporadic, but improved considerably at shorter ranges (10 miles). It is straight-forward to predict that using a 200 watt transmitter and flying at a higher altitude (say 35,000 ft), reliable paging can be expected at ranges of at least 80 miles and reliable paging into dense buildings can be expected at ranges of at least 40 miles.

14. SUBJECT TERMS

15. NUMBER OF PAGES
36

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Same as Report	Same as Report	Same as Report